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# Solving the Food-Water-Energy Nexus One Step at a Time: Modernizing Irrigated Agriculture in Hood River, Oregon

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**Abstract**

Food, water, and energy resources are critical to human survival. They are also interdependent. In the world of *traditional* irrigated agriculture in the US West, especially in arid or semi-arid areas, the Food-Water-Energy Nexus is undergoing severe challenges, including population growth, significant water scarcity, growing demands for environmental and species protection, downward pressure on commodity pricing from globalization, increasing demand and higher costs for energy, and the challenge of climate change. This wicked problem of food, water, water rights, energy, farmers, fish/ecology, and climate change is threatening not only the ability to restore and preserve the stream flows necessary to meet ecological needs, but also the legally mandated flows to senior water users and the economic viability of working rural agricultural landscapes. A case study of the Farmer's Irrigation District in Oregon illustrates how a growing number of Western US irrigation district are modernizing their irrigation systems, labeled here as the Integrated Hydro-Irrigation-Restoration Model, by tapping the power of rivers to fuel new low carbon "small" hydropower facilities and pressurize water deliveries, while simultaneously taking measures to save water, promote less fertilizer usage, increase instream flows, and improve environmental outcomes. The new model is necessarily more responsive to the policy demands emanating from policymakers and environmentalists seeking redress for all parts of the Food-Water-Energy wicked problem, from carbon emissions to more environmentally *and* economically sustainable farming systems/communities.

**Keywords:** agriculture, energy savings, hydropower, irrigation modernization, sustainability, water rights, water savings, wicked problems

## 1. Introduction

Food, water, and energy are critical to human survival. Water acquisition, management, movement, distribution, purification and post-use treatment consume large amounts of energy. At the same time, energy production uses significant amounts of water whether the energy source is fossil fuels, thermoelectric and nuclear power plants, solar farms, hydrological fracking, or biofuels. Traditional hydropower, with reservoirs behind dams, also consumes water through evaporation (U.S. Department of Energy 2014; Scott et al. 2011).

The general problem facing the Food-Water-Energy Nexus currently in the U.S., and elsewhere, is that the combination of population growth, increasing demand and higher costs for energy/electricity, and the challenge of climate change, particularly in arid to semi-arid areas, are likely to create an unsustainable trajectory for water consumption, and by extension the ability to maintain and/or increase agricultural productivity in the future. This emerging problem of water scarcity associated with the Food-Water-Energy Nexus has become even more complicated, and more acute, in rural farming and ranching communities across the U.S. West given the incongruous mix of fully, or over-allocated water rights for streams, traditional irrigation systems predicated on water as a commodity, pressure to maintain or improve crop productivity and economic returns, and the more recent applications of the 1973 federal Endangered Species Act and other environmental protection measures. This is because the environmental measures typically demand that more water remains instream, meaning less is available for traditional, especially consumptive, uses such as irrigated agriculture. Moreover, the structure of the "first in time, first in right" prior appropriation water rights system in western states privilege senior water rights holders, meaning that in dry or drought years, the burden of water scarcity is borne disproportionately by junior rights holders who may not get their water. This problem of water reliability for irrigation systems is likely to be exacerbated given climate change model predictions for the arid and semi-arid regions of the U.S. West and western Canada (Kenney & Wilkinson 2011). In short, this wicked problem of food, water, water rights, energy, farmers, fish/ecology, and climate change is threatening not only the ability to restore and preserve the stream flows necessary to meet ecological needs, but also the legally mandated flows to senior water users and the economic viability of working agricultural landscapes in rural areas (Weber, Lach and Steel 2017).

Taken together, these developments are posing major challenges for traditional irrigation systems, most of which were designed 100 or more years ago to address only the food (agriculture) and water aspects of the larger Food-Water-Energy Nexus.

How can irrigators, farmers, and ranchers, along with other key stakeholders, respond to these challenges and make sure that their irrigation systems are effective across all elements of the Food-Water-Energy Nexus? A growing number of Western US irrigation districts, 44 at last count, (Note 1) are undertaking system modernizations that are about much more than simply employing advanced water delivery infrastructure and on-farm technologies in order to lower system costs, save water, and deliver water more effectively and efficiently to farming operations. These cases also are innovating and transforming their systems to accommodate additional values and goals not typically associated with irrigated agriculture. This new model, labeled here as the Integrated Hydro-Irrigation-Restoration Model, taps the power of rivers to fuel new low carbon "small" hydropower facilities, while simultaneously taking measures to promote less fertilizer usage, increase instream flows, and improve ecosystem health. To the extent that such a system transformation adheres to the comprehensive integrated model, it thus will necessarily be more responsive to the policy demands emanating from policymakers and environmentalists seeking redress for all parts of the Food-Water-Energy Nexus wicked problem, from carbon emissions to more environmentally *and* economically sustainable farming systems/communities (see Table 1; see also Weber 2017). Just as importantly from the irrigators/farmers perspective, these many different policy goals are being achieved without altering the integrity of the existing water rights system.

In places where irrigators have chosen the modernized Integrated Hydro-Irrigation-Restoration Model, are the new systems delivering the expected results? In order to answer this question, this research examines a case of modernization--Farmer's Irrigation District (FID)--in the Hood River Basin of Oregon. This case study demonstrates that the modernized integrated system produces the expected results across the board, thus providing one possible pathway to address successfully this example of the Food-Water-Energy wicked problem.

Table 1. System responsiveness to food-water-energy wicked problem set, farmer's irrigation district (Hood River, Oregon, USA)

| Policy Goals | Existing Traditional Water Delivery System | Integrated Hydro-Irrigation-Restoration System |
|---|---|---|
| **Water Rights System, Integrity of** | Yes, central to system function | Yes, integrity maintained |
| **Energy Production** | No | Yes |
| **Responsiveness to Climate Change** (carbon free energy source) | No | Yes |
| **Ecology/Fish** | No, lack of "fish friendly" screens & fish passage blocked | Yes, screening fixed & fish passage restored |
| **Ecology/Adequate Streamflow** | No | Yes |
| **Water Quality** (meeting CWA temperature standards) | Problematic/ regular exceedances | Yes, in most all cases |
| **Riparian Zone Health** | Poor | Significant & continuing restoration progress |
| **Economic Benefits, General** (water to support on farm revenues) | Yes, water & agriculture revenues | Yes, water & agriculture revenues |
| **Additional Economic Benefits to Users**<br>• lower energy costs<br>• increased revenues from water sales<br>• more water to use<br>• lower liability costs | No | Yes, on all counts |
| **Water Reliability** (high certainty/guaranteed delivery to *all* users) | Problematic in dry and/or drought years | Yes/High, even in dry and/or drought years |

## 2. Background: Hood River County and Irrigation Modernization

Hood River County is located in the Columbia River Gorge about 65 miles east of Portland, Oregon. It is a 100% rural county with the town of Hood River (population 8341) as the economic hub. It has long been known for producing high quality tree fruits—pears, apples, and cherries—including 25% of all pears sold in the US. As of 2021, the county is home to 24,057 people and 8,949 households, with an annual GDP of approximately $1.5B employing 12,200 workers. Roughly 15% of these workers are in the agricultural sector and are responsible for $135 million in annual GDP, with 98.5% of the value produced by tree fruits (DataUSA 2022; US Census 2022).

Farmer's Irrigation District (FID) is one of five irrigation districts located in north central Oregon's Hood River Basin in the Columbia River Gorge. Farmers within FID primarily grow pears (more than 70% of total crop production), followed by apples and cherries (Perkins, 2013, p. 6). FID supplies water to 1,722 irrigators across 5,800 acres using three main canals totaling over 60 miles in length. Starting in 1874, the water distribution system consisted of hand dug ditches and open wooden flumes, while relying on 34 unscreened diversions (Perkins, 2013). The system was highly inefficient, with roughly 50% of conveyed water lost through evaporation, seepage, and operational spills, which result from the need to "push" more water through the system than is actually needed due to the physics associated with delivering water through open canals to water users at the end of each ditch. Canal overflows and breaches interrupting water delivery were also common due to the consistent debris flows from Mt. Hood's melting glaciers. System vulnerability to yearly problems from land/mudslides, debris flows and flooding generated hundreds of thousands of dollars in annual maintenance and repair costs for FID. In addition, farmers used individualized on-farm pumps that added significant energy-related operational costs. By the early 1980s, the inefficient irrigation system, combined with price competition from expanding globalization that lowered agricultural prices, made Hood River farming less economically sustainable. As a key actor involved in FID modernization stated:

*The key factor [for modernization] was survival. The inefficient delivery of water to the irrigators*

> *really eroded security and reliability. [FID's] system was falling apart and being able to modernize that system ensured that they would be able to provide reliable water [deliveries]* (personal interview, 05/24/2018).

In response, FID decided to start replacing the open canal system with enclosed conduit pipes starting in the mid-1980s, using the natural fall in elevation across the district to pressurize the water delivery system. Also included in this initial phase of modernization were the construction of two new, small hydropower generating plants, which do not have dams or impoundments, and where water is returned to streams after passing through the plants or is otherwise used to irrigate crops, both made possible by the new enclosed pipelines that also resulted in pressurized water deliveries and water savings. The hydropower energy production was designed to (1) reduce energy costs for FID, (2) generate enough revenue to pay off the $12 million in debt stemming from the initial modernization efforts and the addition of the new hydropower units, and (3) produce enough extra revenue to finance modernization of the remaining FID canal system.

However, in 1986 the Oregon legislature passed a rule (OAR 690-51-200), which established that "[n]o project shall be approved that may result in mortality or injury to an individual anadromous salmon or steelhead or loss of any salmon or steelhead habitat" (6). This posed a serious problem for FID's need for new water rights associated with their planned small hydropower plants. Faced with the risk of not obtaining water rights under the new regulatory framework, FID's manager initiated an open dialogue and coordination with the Oregon Department of Fish & Wildlife [ODFW], NOAA National Marine Fisheries Service [NMFS] and the U.S. Fish and Wildlife Service (USFWS.) to rectify this situation. The agencies required FID to install fish screens at every diversion in order to keep fish out of irrigation canals, where they often died due to entrainment, warmer water temperatures, and dewatering of canals out of irrigation season (Bryan, 2008). In 1990, FID finally secured their year-round water rights for hydropower use (which includes winter flow rights) and, as part of the deal, the District entered into an agreement with ODFW to maintain minimum flow levels in Green Point Creek (Bryan, 2008) and to revise the terms and conditions for the FID hydropower system, which included new fish habitat protection measures, flow monitoring, and further conversion of open canals to buried pipes in and around Green Point Creek (ODFW, 2019).

These developments were followed by three major events during the rest of the 1990s that further incentivized FID's ongoing modernization efforts: the adoption of FID's first Water Management and Conservation Plan (WMCP) in 1995, a severe weather event in 1996, and three ESA listings in the late 1990s. Additionally, 1,455 individual on-farm electric irrigation pumps were converted into FID's centralized pumping stations, creating dramatic energy savings. The push for modernization also involved the installation of digital telemetry to monitor water flows and the growing adoption of advanced on-farm technologies by FID's individual farms.

First, in 1994 Oregon regulations (OAR 690 Division 86) started requiring irrigation districts and other major water users/suppliers to develop Water Management and Conservation Plans (WMCP). FID became the first irrigation district in the state to meet this mandate by writing a plan in 1995. In 1996 FID took the added step of developing and adopting a Sustainability Plan that specified their strategies for achieving their WMCP goals (Perkins, 2013).

- Eliminating water flow losses by enclosing open canals and laterals.
- Promoting efficient water usage through improvements in on-farm water delivery (irrigation) technologies.
- Reducing energy usage by eliminating private on-farm pumps and converting to a centralized pumping scheme.
- Promoting stream and riparian zone health through conservation projects and additional instream flows.

Second, a weather-related event in February 1996 caused severe damage to FID's irrigation system. Several days of heavy rain rapidly melted the snowpack on Mt. Hood, which caused large-scale flooding. The Hood River and its tributaries carried massive amounts of rocks, woody debris, sediments and mud into the FID canal system, collapsing canal sections in some places and filling others, while also destroying 34 diversion structures, roads, and other FID facilities (Perkins, 2013; Bryan, 2008). District patrons ended up viewing this "catastrophe" as "an opportunity for a leap forward in the modernization process" (Bryan, 2008; Fernandez-Guajardo 2020). The massive damage to the system spurred more support for the ongoing enclosed piping projects and led many to seize the opportunity to replace the old high maintenance, hard to clean, and inefficient "vertical" fish screens with a new, more effective and fish friendly design promising lower operations and maintenance (O&M) costs. The primary problem, however, was that such a screen did not exist except as a "not-yet-tested" prototype created by

FID employees. The innovative "horizontal" screen design was installed by two growers at one diversion point in less than a week's time. As noted by Bryan (2008):

> *The screen worked well. It required little cleaning, fish passed upstream and downstream without injuries of any kind, and sediment and debris did not foul the screen [given a self-cleaning mechanism], …[thus] decreasing operation and maintenance costs* (5).

Working together with multiple stakeholders—Confederated Tribes of Warm Springs, US Bureau of Reclamation, NOAA-NMFS, USFWS, ODFW--FID developed and tested the new horizontal design, which ended up meeting all the technical requirements of the fish agencies. As part of this testing, FID realized that hydroelectric revenues were also likely to increase because the screens provided reliable, uninterrupted, and steady diversions of FID's water rights. FID started installing the new screens in the late 1990s on Hood River tributaries, with a large screen installed on the main stem of the Hood River in 2003. By 2005, FID had obtained US patents for their innovative design, and in 2011, the "Farmer's Screen" received federal approval from NOAA-NMFS as an ESA-compliant technology (Perkins 2013; Fernandez-Guajardo 2020). The District also took advantage of the weather-related system damage by revamping and reducing their irrigation system diversion points downwards from 34 to only ten, all of which are "fully screened and fish safe" (FID 2011, 4).

Third, an added incentive to continue modernization efforts came from three ESA listings of fish species endogenous to the Hood River Basin. Each species was listed as threatened, with Bull Trout in 1998, Steelhead in 1998, and Spring Chinook Salmon in 1999. These new challenges meant that FID's prior efforts to provide minimum instream flows per ecological standards set by ODFW, to remove fish passage barriers and improve stream habitat, and to install the new fish-friendly screens at water diversion points were of increasing importance to FID's water management decisions (Coccoli 1999).

Fourth, starting in the 1980s, FID leaders concluded that system modernization should include the gradual conversion of 1,455 electric irrigation pumps owned and operated by individual growers into a centralized district pumping stations. Centralization was expected to reduce O&M costs for individual farmers by making it easier to manage and account for glacial silt flows in water and increase water reliability. Just as critical, the new centralized pumping stations were expected to provide significant reductions in energy (electricity) costs. To date, all 1,455 pumps have been transferred to the new centralized system; 404 pumps were transitioned during the 1980s, 942 in 2004, 51 in 2010, and 59 in 2013.

Fifth, irrigation system modernization involved the system-wide installation of highly accurate digital measurement telemetry capable of monitoring flows from a computer (or smart phone), rather than moving from diversion to diversion to manually read flows. The new telemetry system included an alarm feature that would trigger and send warnings to FID managers when anomalies occurred, meaning system problems could be targeted and attended to promptly, ensuring restored flows much sooner than with the old system. And just like the new horizontal self-cleaning fish screens, telemetry reduced O&M costs, thus increasing available capital for system improvements (Bryan, 2008).

Finally, another relevant part of the modernization story for FID involves the adoption of new more water efficient, on-farm technologies by individual growers such as low flow micro-sprinklers, drip irrigation, digital telemetry water measurement systems, soil moisture sensors, and solid "poly" (plastic) pipe (in place of hand-moved and -placed, multi-section metal pipes). FID managers estimate that, by 2012, 95% of all farms served by the system had made these conversions, with 97% of the agricultural acreage employing micro-sprinklers and the remaining 3% utilizing drip irrigation (FID 2019). As will be seen in the results section below, these on-farm changes conserved roughly one out of every four gallons saved in total by the overall modernization efforts, while also saving fertilizer and helping to improve crop productivity. In short, by 2012, the District had "met almost all of the goals in the original 1995 Water Management and Conservation Plan" (Perkins, 2013, 15).

## 3. Methods

The research relies almost entirely on primary source documents produced by US and state government agencies, NGO reports, secondary sources, and research articles specific to the case and the Hood River Valley of Oregon. This material was supplemented with unstructured personal interviews and emails with current and former FID leaders, along with FID patrons/farmers, NGO officials, government agency officials, and environmental advocates in order to help develop the case context and the rationale for adopting the new modernized irrigation system. Several of these individuals also provided a critical eye after the article was written as a method of checking the accuracy of both the case study story and relevant facts.

## 4. Results

As the Farmer's Irrigation District (FID) piped more canals, centralized more on-farm irrigation pumps, protected more fish with minimum instream flows and innovative new horizontal fish screens, maximized the in-conduit, small-scale hydropower generators, and added digital telemetry for water flow management, the Integrated Hydro-Irrigation-Restoration Model produced a series of significant results that "helped to ensure the sustainability of these family farms for another 100 years" (personal interview, 2/20/21), including:

- Massive water savings and increased, more reliable water deliveries throughout the FID system
- Dramatic energy savings and revenue impacts from the hydropower plants and pump centralization
- Fewer carbon emissions
- Less water and fertilizer used; higher crop productivity and, by extension, increased farm income
- Lower costs for Operations & Maintenance (O&M) as well as insurance.

### *4.1 Water Savings and Increased, More Reliable Flows*

The FID's original open canal and wooden flume irrigation conveyance system, as described above, was subject to severe water losses averaging over 50% in a given year. Modernization replaced this inefficient water delivery infrastructure with enclosed conduits buried in the ground, which promised tremendous water savings and increased, more reliable water deliveries. Following Perkins (2013) example, this study selected 1995 as the baseline pre-modernization year due to spotty water delivery record-keeping prior to 1995, the adoption of the first Water Management and Conservation Plan in 1995, and the close proximity to the weather-related disaster in 1996, which led to additional reliability with the installation of the new horizontal, self-cleaning fish screens. As a comparison year, 2011, was selected, again following Perkins (2013; see also WMCP 2011), and because by this time 95.6% of all pumps had been centralized, 85.1% of the FID system was receiving water via enclosed pipelines, and 95% of all farms had converted to either micro-sprinklers or drip irrigation.

Table 2. Total water savings from modernization

| | **Irrigation Farms** | **Irrigation/ Residential** | **Spray & Frost Water** | **Total Water Used** |
|---|---|---|---|---|
| **1995** | 24180 | (incl. in Farm #) | 3684 | 27864 |
| **2011** | 8538 | 4330 | 184 | 13052 |
| **Water Savings** | | | | **53.2%** |

Table 2 shows that in 2011 FID system and on-farm modernization saved 14,812 acre feet, or 53.2% of the water used back in 1995, when only a handful of farmers had modernized their operations. Table 3 displays the water savings resulting from the on-farm modernization alone, showing that on-farm adoption of modernized water delivery technologies saved 3,353 acre feet in 2011 compared to the 1995 water usage. This means that 77.4%, or more than 3 of every 4 gallons saved by modernization stems from the larger FID "system" modernization, while the remainder, 22.6%, or almost 1 gallon of every 4, (Note 3) is contributed by on-farm technology upgrades. A key point here is that the new efficiency gains from on-farm modernization likely would not have occurred without the systemwide modernization, because system-based pressurization resulted in pressurized water deliveries to farms. Without pressurized deliveries individual farmers would have to pressurize their own on-farm systems, and bear the cost of doing so, in order to install on-farm technologies and realize the associated efficiencies in water conservation, as well as labor and management costs. These water savings allowed FID to conserve water to maintain instream flows for fish, thereby reducing water temperatures (maintaining cold water for cold-water fisheries), and helping to achieve other riparian zone restoration objectives, while also increasing water availability for on-farm crops by better than 50% vis-à-vis the old open canal system.

Table 3. FID/Annual on-farm water savings from micro and drip conversions

| Type of Conversion | Farm Acres Covered | Efficiency/ Savings Rate | Gallons/ Acre Saved | Total Gallons Saved | Total Acre Feet Saved |
|---|---|---|---|---|---|
| Micro-Sprinkler | 3913 (97%)* | 47.6% | 265,735 | 1.04 Billion | 3192 |
| Drip | 121 (3%) | 78.0% | 435,448 | 52.7 Million | 161 |
| | | | | | **3353** |

*The total number of farm acres in the FID system is 4,246, of which 95% are modernized, or 4,034 acres of on-farm modernization. The on-farm modernization is further spilt into micro-sprinklers on 3913 acres (97%) and drip systems on 121 acres (3%) (see WMCP 2011, 18-19).

Sources: Irrinet (2007); 20 OWEB Reports of FID On-Farm Modernization; Water Management and Conservation Plan (2011)

*4.2 Energy Savings and Revenue Impacts*

An essential part of FID's overall modernization process created and captured significant energy savings, or conservation, by converting on-farm electric water pumps to centralized, district-owned pumping stations. While FID does not have a full set of energy usage data for the baseline year of 1986, when both hydro plants began operations and were synched to the Northwest's electrical power grid, or across their entire service area, Energy Trust of Oregon (2020) and Perkins (2013) report the degree of energy conservation achieved by converting to centralized pumping stations. These cases—Indian Creek Corridor Project (ICCP), Lower District Pipe Pressurization (LDPP), and Dee Block—cover 1,585 acres total and show energy savings rates from 63.7% to 77.9%. When adjusted to a weighted average, the overall savings rate equals 73.1% (Table 4). With this figure in hand, and using monthly energy consumption and energy (kWh) cost records from FID's utility provider, PacifiCorp, the energy and money saved yearly by pump centralization were calculated.

Table 4. FID energy savings from centralized pump stations

| Pump Efficiency Projects | Year | No. of Acres Served | % Energy Savings from Central Pumps |
|---|---|---|---|
| **LDPP** | 2010 | 363 | 63.7% |
| **Dee Block** | 2018 | 870 | 75.0% |
| **Indian Creek Corridor** | 2009 | 352 | 77.9% |
| | | **1585** | **73.1%** |

(weighted avg)

Table 5 shows these results for the 11-year period from 2008 through 2018. Applying the 73.1% savings rate from Table 4, as well as average kWh rates for each year and the extent of centralization for the individual on-farm pumps, FID has been able to conserve 11.2M kWh during this time period. And in 2018, when pump centralization was almost 100% complete, the annual energy saved amounted to 1,365,736 kWh, which is enough to power 1,297 average-sized homes each year.

The energy conservation from modernization translates into significant cost savings as well. From 2008 through 2018, FID paid an average of $39,073 per year for their district's energy needs, with average savings each year due to pump centralization totaling over $90,000, or more than $1M over the 11-year period (see Table 5).

Table 5. FID energy consumed and saved from pump centralization, 2008 - 2018

| Year | kWh Consumed | Energy Costs | % Pumps Centralized | kWh Conserved | Energy Cost Savings | Energy Costs Pre-Modernization |
|---|---|---|---|---|---|---|
| **2008** | 262,202 | $ 19,465 | 92.1% | 540,255 | $ 40,107 | $ 59,572 |
| **2009** | 339,560 | $ 24,329 | 92.1% | 699,647 | $ 50,129 | $ 74,458 |
| **2010** | 409,280 | $ 29,590 | 95.2% | 936,646 | $ 67,717 | $ 97,307 |
| **2011** | 412,240 | $ 35,012 | 95.2% | 943,420 | $ 80,126 | $ 115,138 |
| **2012** | 463,360 | $ 40,653 | 95.2% | 1,060,409 | $ 93,035 | $ 133,688 |
| **2013** | 488,880 | $ 43,099 | 95.2% | 1,118,813 | $ 98,633 | $ 141,732 |
| **2014** | 508,080 | $ 47,473 | 95.2% | 1,162,752 | $ 108,643 | $ 156,116 |
| **2015** | 451,200 | $ 42,842 | 95.2% | 1,032,581 | $ 98,045 | $ 140,887 |
| **2016** | 540,960 | $ 50,833 | 95.2% | 1,237,999 | $ 116,332 | $ 167,165 |
| **2017** | 502,960 | $ 47,713 | 95.2% | 1,151,035 | $ 109,192 | $ 156,905 |
| **2018** | 508,950 | $ 48,798 | 99.7% | 1,365,736 | $ 130,946 | $ 179,744 |
| **TOTAL** | **4,887,672** | **$ 429,807** | | **11,249,293** | **$ 992,906** | **$ 1,422,713** |
| **Annual Average** | **444,334** | **$ 39,073** | | **1,022,663** | **$ 90,264** | **$ 129,338** |

The other, much larger side of the energy equation with respect to irrigation modernization for FID is the generating capacity of the two in-conduit small hydropower turbines that are integrated into the pressurized water conveyance system. Prior to modernization, FID's business model did not produce energy, either for local use or for sale back to the grid. The energy produced by FID's two small hydro units is purchased by PacifiCorp using long-term contracts. As Table 6 shows, the annual energy *produced* by the two generators (in kWh) is more than an order of magnitude higher than the energy *saved* from the pump centralizations. The average annual energy produced from 2008 through 2018 equals approximately 23.4M kWh, with a high of almost 25.7M in 2010 and a low of 21.2M in 2016. The total energy produced is equivalent to roughly 9% of the total annual energy needs of FID's home county, Hood River, and is enough energy to power, on average, 23,794 average-sized (2000 square feet) homes in Oregon each year. (Note 2)

These hydropower energy outputs translate into average annual revenue for FID of over $1.9M, with the revenues ranging from roughly $1.5M in 2016 up to almost $3.1M in 2010, with the 11-year total hydropower revenue for FID equaling more than $21M. Stated differently, 93.4% of the overall energy equation—saved and produced—comes from the small hydropower generating plants.

Table 6. FID hydro energy generation and revenue, 2008 - 2018

| | kWh Produced | Energy Revenue |
|---|---|---|
| **2008** | 22,793,504 | $ 2,606,964 |
| **2009** | 22,859,501 | $ 2,662,737 |
| **2010** | 25,678,299 | $ 3,066,310 |
| **2011** | 25,133,239 | $ 1,504,830 |
| **2012** | 24,377,298 | $ 1,578,289 |
| **2013** | 22,759,412 | $ 1,477,026 |
| **2014** | 22,998,240 | $ 1,601,266 |
| **2015** | 21,167,857 | $ 1,573,951 |
| **2016** | 21,156,339 | $ 1,473,402 |
| **2017** | 25,037,070 | $ 1,743,895 |
| **2018** | 23,426,213 | $ 1,753,435 |
| **TOTAL** | **257,386,972** | **$ 21,042,105** |
| **Annual Average** | **23,398,816** | **$ 1,912,919** |

Source: FID Utility Bills and Hydrologs

### *4.3 Carbon Savings*

The energy savings from pump centralization and the energy produced by the small hydro plants combine to affect another key consideration in 21st Century policy debates: avoided carbon emissions. Using data from 2016 (Northwest Power and Conservation Council 2018), we find that in the Pacific Northwest region of the US the annual average $CO_2$ emissions production rate from all electricity generation is 1.83 pounds per kWh. This means that FID's small hydro sources of energy, which are low-carbon, have an annual average *avoided* $CO_2$ emissions rate of 1.83 pounds/kWh produced, as do any energy savings stemming from more efficient centralized pumping systems. Table 7 translates the FID energy production and savings kWh numbers into pounds of carbon avoided. Using the same 11 years of data from 2008 through 2018, FID's modernized irrigation district *avoided* 471,018,159 pounds of carbon during that time period due to new hydropower produced, and 20,586,206 pounds of carbon due to pump centralization. Together, the total of 491.6 M pounds of carbon avoided is the equivalent of taking 47,354 cars off the road, while the total annual average of carbon avoided equals almost 45,000,000 pounds or 4,305 cars off the road. (Note 4)

Table 7. FID system, carbon offset, 2008 - 2018

| | Small Hydro kWh Produced | Hydro, Carbon Offset (lbs) (NWPPC 2018) | Pump Efficiencies kWh conserved | Pump Efficiencies Carbon Offset (lbs) (NWPPC 2018) | Total Carbon Offset (lbs) |
|---|---|---|---|---|---|
| **2008** | 22,793,504 | 41,712,112 | 540,255 | 988,667 | 42,700,779 |
| **2009** | 22,859,501 | 41,832,887 | 699,647 | 1,280,354 | 43,113,241 |
| **2010** | 25,678,299 | 46,991,287 | 936,646 | 1,714,062 | 48,705,349 |
| **2011** | 25,133,239 | 45,993,827 | 943,420 | 1,726,459 | 47,720,286 |
| **2012** | 24,377,298 | 44,610,455 | 1,060,409 | 1,940,548 | 46,551,004 |
| **2013** | 22,759,412 | 41,649,724 | 1,118,813 | 2,047,428 | 43,697,152 |
| **2014** | 22,998,240 | 42,086,779 | 1,162,752 | 2,127,836 | 44,214,615 |
| **2015** | 21,167,857 | 38,737,178 | 1,032,581 | 1,889,623 | 40,626,802 |
| **2016** | 21,156,339 | 38,716,100 | 1,237,999 | 2,265,538 | 40,981,639 |
| **2017** | 25,037,070 | 45,817,838 | 1,151,035 | 2,106,394 | 47,924,232 |
| **2018** | 23,426,213 | 42,869,970 | 1,365,736 | 2,499,297 | 45,369,267 |
| **TOTAL** | **257,386,972** | **471,018,159** | **11,249,293** | **20,586,206** | **491,604,365** |
| **Annual Average** | **23,398,816** | **42,819,833** | **1,022,663** | **1,871,473** | **44,691,306** |

### *4.4 Less Water, Less Fertilizer, and Higher Crop Productivity*

In irrigated farming systems, applying water and fertilizer to crops at the right time and in the proper quantity are essential to producing a marketable, income-producing crop, as it can have a direct, positive impact on crop productivity. The general inefficiencies of the old FID water conveyance system, along with the on-farm use of gravity-fed, hand-set, multi-piece metal irrigation pipes, inefficient high-flow broadcast sprinklers, and lower efficiency, solid broadcast fertilizer applications were able to produce solid crop productivity numbers for most FID growers prior to modernization. Yet, as noted above, starting in the 1980s, globalization and the pressures from price competition placed an additional premium on increasing the efficiencies associated with water and fertilizer use, as well as crop productivity improvements. FID growers responded by adopting new, more-water-efficient on-farm technologies such as low flow micro-sprinklers, drip irrigation, digital telemetry water measurement systems, soil moisture sensors, specialized computer software, and solid "poly" (plastic) pipe for delivering on-farm water to crops. The combination of these modernization efforts allow farmers to deliver water and fertilizer in a more targeted fashion with just the right amount of water at the right time. The resulting effect of FID's system modernization, together with these on-farm upgrades, is higher crop productivity. Anecdotes from FID officials and growers point to higher crop productivity of marketable fruit (e.g., pears, apples) in the 30% to 100% range. An FID official notes that "most of our growers are seeing large increases in fruit production, many are now producing 50% more than before [modernization]" (personal interview, 10/15/19). One grower, relying on 40 years of data for their operation, went so far as to claim that after system and on-farm modernization he is "now able to produce twice the tonnage of green pears, all very high quality, at three times the profit, using two-thirds the pre-modernization [1995] volume of water" (personal communication, 3/16/19). He adds that he and "most other orchardists on the upper western side of Hood River County would have been bankrupt without the [FID] system improvements" (personal communication, 3/16/19).

The pressurized water from the conduit pipes also allow the new closed poly pipes on-farm to change fertilizer applications from traditional solid broadcast types (broadcast from machinery across the ground) to fertigation, which mixes nitrogen with irrigation water by injecting fertilizer solution into the flowing water of an irrigation system. The switch to fertigation means that fertilizer is more directly targeting specific plants and that more accurate, smaller amounts of fertilizer are applied, often 15% to 30% less each year. In a Hood River Basin study, Yin, Bai and Seavert (2009), find that split fertigation (applied twice each year) produced the same amount of overall fruit, yet also produced sizable increases in "marketable" fruit of 11% and over 20% in their two test orchards (see also Yin, Huang and le Roux 2011).

In sum, the "fish and water savings-oriented" modernization mindset that was captured in the 1995 WMCP and operationalized by the FID was leading to a virtuous cycle of prosperity for the district and its growers.

*4.5 Lower Costs for O&M and Insurance*

As previously noted, FID's modernization transformed the open canals and flumes into buried, closed conduit pipes. These changes significantly reduced operations and maintenance (O&M) costs in several ways. First, consolidating almost 1,500 separate pumps into a centralized pumping system led to a significant decrease in O&M workload and costs. Second, the solid, closed-conduit pipelines are rated as having a 100-year life with little to no need for annual maintenance or repair. This compares to constant annual efforts to maintain, clean, and keep the canal system open so it could deliver irrigation water. Part of these O&M savings from modernization stem from the new horizontal, self-cleaning fish screens, which number only ten, compared to 34 diversions in the old open canal system, which required constant O&M vigilance. Third, modernization virtually eliminated the FID's vulnerability to yearly problems from land/mudslides, debris flows, flooding, and other weather-related events, which, as seen below, caused, on average, hundreds of thousands of dollars in annual maintenance and repair costs. Fourth, the incorporation of digital measurement telemetry provided a way to decrease the labor costs associated with manually reading stream flow gauges because flow data became constant and could be tracked using computers in FID's main office. Digital telemetry also facilitated faster O&M response times to problems and/or disruptions in water deliveries since the continuous data feed alerted FID staff to such issues immediately, which decreased the amount of time the FID water conveyance system was either offline or operating at below 100% capacity. Fifth, the installation of solid poly pipe on individual farms decreased farm labor costs vis-à-vis traditional manual, hand-set irrigation pipe systems.

In short, the modernization of the FID water conveyance system, along with on-farm modernization efforts, eased the O&M burden by reducing costs significantly. A study by Farmer's Conservation Alliance (2019) estimated that FID's savings in annual O&M costs reached $2.3M over 30 years (roughly $77,000/year), while individual growers reaped a total of $900,000 in O&M savings over the same 30-year period. Additional O&M savings were captured from the avoided costs associated with rebuilding the old open canal system after the massive flood and debris flow damage in 1996. FID estimated that the cost of system reconstruction and repair due to that one severe weather event was $5.1M, with $1.5M to repair damage to three different collection system canals in the upper district and $3.6M for the Low Line Canal (Hood River Watershed Group Meeting Minutes, February 1996). When such severe weather events are factored in, and assuming a frequency of once every 30 years (or several less severe events over the same time period), the total O&M savings accruing to FID over 30 years of modernization equals $7.4M, or almost $250,000 saved each year (Fernandez-Guajardo 2020, 89).

In addition to these O&M cost savings, there were liability and overall insurance costs savings from system modernization, including (1) the closed conduit system reduced FID's liabilities related to injuries and deaths from people falling into open canals, and (2) reduced labor overall meant fewer opportunities for injury and Workman's Compensation claims.

## 5. Conclusion

The modernization of the Farmer's Irrigation District in Hood River, Oregon heralds one potential pathway for overcoming the many difficult challenges posed by the wicked problem of the Food-Water-Energy Nexus in the 21st Century. The case shows how the Integrated Hydro-Irrigation-Restoration Model not only can improve crop and labor productivity, farm incomes, and water use efficiency, but also can provide a predictable revenue stream for irrigation districts to support regular operations and maintenance, save enormous amounts of water, save on electricity costs, place more water instream for fish and ecosystem protection, and, in the era of climate change, create a new source of clean reliable power. Just as importantly, the multi-faceted Food-Water-Energy problem is solved and major environmental protections are achieved in this case, including added help for endangered species, *without* changing the underlying system of Western US water rights, the prior appropriations doctrine, thereby avoiding a major political fight that environmentalists may well lose and keeping intact rural agriculturally based communities that are more environmentally *and* economically sustainable.

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## Notes

Note 1. Thirty of these are in Oregon, with 2 each in Washington and Colorado, and one each in Alaska and

Montana (Farmer's Conservation Alliance, personal communication March 25, 2021; DOE 2015).

Note 2. The average annual kWh usage for a 2000 square foot home in Oregon is 976 kWh (Electric Choice 2021).

Note 3. The on-farm water savings rate corresponds with the 24.4% savings rate estimated for on-farm conversions at the neighboring East Fork Irrigation District (EFID) in the Hood River Water Conservation Strategies report (Theiman, Salminen, and Christensen, 2016). The EFID was at a similar stage of system modernization in 2016 as FID was in 1995.

Note 4. The conversion factor used to turn metric tons of carbon into cars taken off the road is 4.71 metric tons CO2E/vehicle/year, while the conversion factor to turn pounds of carbon into metric tons is .00045369 per pound (EPA 2018).